Wind Charged Battery Storage Facility

Utility Post-Consumer EV Batteries for Peak Grid Distribution

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Abstract

The proposed concept is a means to store wind energy in electric vehicle (EV) batteries after they have degraded past their usable life in consumer vehicles extending the life cycle of the batteries. With the recent excitement surrounding EVs, a surplus of post consumer batteries and reject batteries is expected a few years down the road. The batteries would be utilized to store electricity during off-peak demand periods and redistribute to the grid during on-peak demand periods for grid stabilization. Based on the Michigan Renewable Portfolio Standard of 10% electricity generation from renewable sources by 2015, Michigan will have an adequate amount of wind capacity to charge the EV battery wind storage facility and meet all of Michigan's 2015 consumer EV requirements.

Keywords

Battery Energy Storage; Electric Vehicles; Electric Vehicle Batteries; Michigan Wind Energy; On-peak/Off-peak Grid Stabilization

Introduction

As the electrical demand throughout the developed and developing world increases, alternative sources of additional energy are currently undergoing research, experimentation, and development. As a result, renewable energy sources such as wind, solar, and biomass have emerged as both primary and secondary sources of additional energy to help meet the need of today's world and the world years from now. Among the current technologies available today, harnessing energy from the wind is proving to yield some of the most significant results.

Harnessing wind energy does pose a few challenges to overcome. One such challenge with utilizing wind energy on a utility grade scale is the inability to adequately control wind availability. Wind energy production could easily occur during off peak hours when the additional energy is less valuable due to lower grid demand. Nearly all of the electricity currently produced by wind turbines cannot be stored and must be used immediately if demand is present. This is an active area of research and one that can be solved through use of batteries.

Reduced electricity demand during the off peak hours may in some cases require wind farm producers to shut down the turbines during this time to prevent exposing the electrical grid to excessive energy. The potential wind energy from evening and early morning would go uncaptured if the turbines are shut down. This is particularly troublesome due to generally greater wind intensity levels during the evening. To utilize the potential wind energy available during evening hours, an energy storage system will be required to capture and then discharge the energy captured during an appropriate time.

In place of shutting the turbines down during evening hours, an energy storage facility utilizing post-manufacture and post-consumer EV batteries would provide a venue for capturing off-peak energy for distribution at a later time. The captured evening hour wind energy would help reduce on-peak grid load. However, the batteries active time would depend on the energy captured during the previous evening. Coupled with the variability associated with sufficient wind availability, an exact figure describing how long the storage facility would be able to assist the grid is unknown.

Michigan Wind Energy Availability

West Michigan is advantageously positioned for working with battery manufacturers and capturing wind energy. Wind energy availability from the Great Lakes and inland Michigan is set to expand considerably over the next several years due to the state of Michigan renewable portfolio standard (RPS). The RPS calls for 10% of the states electrical demand to come from renewable energy sources by the year 2015.

Wind is currently the largest source of this renewable energy.

Michigan Renewable Portfolio Standard (RPS)

Public Act 295, signed into law in 2008, developed a new RPS for Michigan which calls for 10% of the state's electricity generation to come from renewable sources. The act promotes clean and renewable energy through the implementation of standards that will provide greater energy security and diversify the energy resources used to meet consumer needs [1].

As seen in Table 1, the RPS will increase annual renewable electric generation in Michigan by 7072 GWh. Assuming a 25% wind capacity factor, if 7072 GWh are to be achieved by wind energy, then 3230 MW of new installed wind projects are required by 2015.

TABLE I EFFECT OF RPS ON WIND ENERGY GENERATION

Current Status		
Current Production	111,551	GWh/yr
Renewable Portfolio	4083	GWh/yr
Renewable %	3.66	%
Michigan RPS 2015		
Standard	10	%
2015 Renewables Req.	11,155	GWh/yr
Installed Capacity Req.	3230	MW

Of currently available sources for renewable energy, wind will specifically make up a considerably large portion installed for the RPS, as shown in Fig. 1.

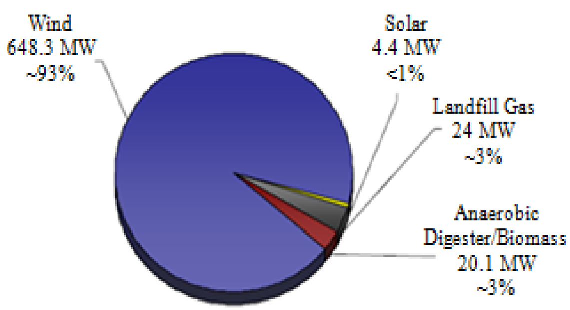

FIG. 1 NEW CAPACITY (MW) BY TECHNOLOGY IN MICHIGAN IN 2012

Michigan Potential Wind Capacity

Michigan's current wind capacity currently lags behind other states, predominantly in the west and mid-west. However, the state's overall position is set to improve considerably with the installation of additional wind farms to meet the upcoming 2015 RPS. Analysing Michigan's geography and wind flow patterns has given researchers insight as to how much wind energy may be available in the state. These figures, for both onshore and offshore wind energy are as follows [2]:

- Onshore:16.5 GW
- Offshore: >25 GW

Using these numbers with a 25% wind capacity factor gives an estimated annual electricity production of:

- Onshore: 36,137 GWh
- Off shore: >54,750 GWh

Added together, the onshore and offshore electricity production is equivalent to about 80% of Michigan's current electricity production from all sources of energy in 2010 [3]. Offshore wind turbine projects are still considered a topic of debate. However, their construction is likely inevitable as fossil fuel sources become more expensive and limited.

Electric Vehicle Production and Growth

The proposed battery facility hinges upon the availability of used EV batteries from both consumer vehicles and manufacturing facilities. Projections regarding the supply of potential batteries vary; however, annual sales are projected to increase annually. These additional EV sales will help supply the facility with the required number of batteries.

Projections

Based on projections and figures from the Energy Information Administration's Annual Energy Outlook, Fig. 2 shows projected EV sales each year through 2035, and Fig. 3 shows cumulative projected EV sales through 2035 [4]. Fig 2 shows two different kinds of electric vehicles; those with a projected travel distance of 40 miles on one full charge and those with a projected travel distance of 100 miles on one full charge. As battery technology improves, vehicles with higher storage capacities and greater efficiency will likely emerge, further increasing the capacity of the battery facility.

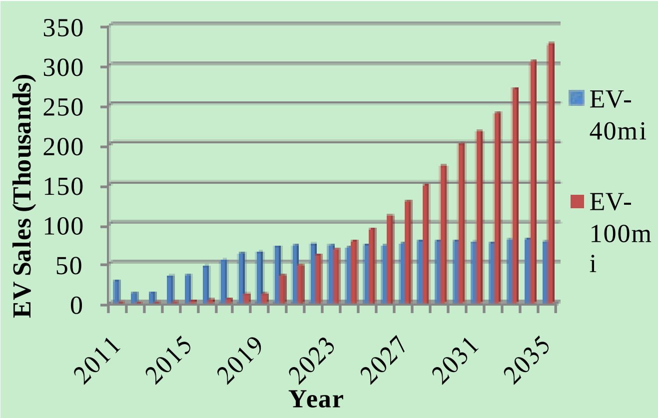

FIG. 2 ELECTRIC VEHICLE SALES PROJECTIONS THROUGH 2035

Projections indicate that by 2015, approximately 135,000 EVs will have been sold for consumer use. This figure is expected to increase to approximately 4.1 million EVs by 2035.

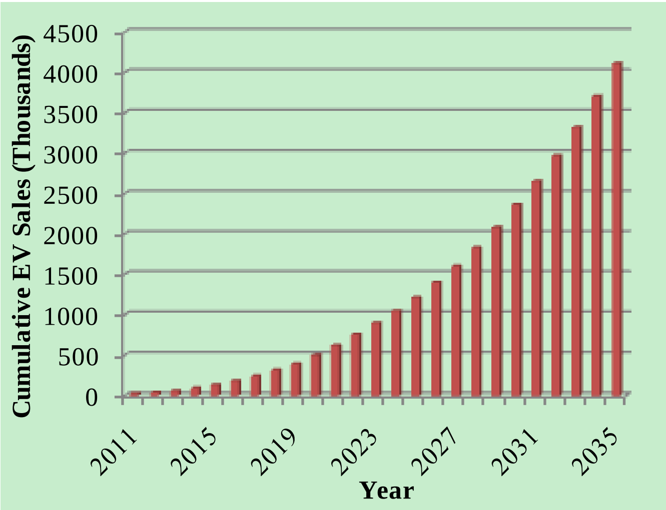

FIG. 3 ELECTRIC VEHICLES ON THE ROAD BY 2035

Emerging Technology

Current lithium-ion battery technology is limited by its energy density. Energy density is a measure of how much energy can be stored in a given volume. Energy density is an extremely important measure in regard to EVs. The energy capable of being stored in EV batteries will ultimately play a large role in determining the vehicles overall range, making designs and materials with a higher energy density more attractive.

While current EVs will allow the consumer to travel only about 30 to 40 miles on electric mode (Chevy Volt) or upwards of 100 miles (Nissan Leaf) before switching to its internal combustion engine, future battery technologies look very promising. Different areas of research are looking to improve different areas of current electric vehicle battery technology; namely energy density and charge time.

Lithium air batteries are the most promising of these up and coming technologies, claiming up to 10 times the energy density of current lithium-ion batteries. IBM, Argonne National Lab, and GM are all currently working to put out a prototype and have them in production by 2020 [5][6][7].

Research has also shown that using a titanium anode in the batteries, degradation of cells can be prolonged, giving a longer life to EV batteries as well as allowing safer faster charging [8]. By using lithium-titanate, a battery can be charged to 80% of its capacity in less than 30 minutes [9].

Department Of Energy Grants

As a part of their plan to help the recovering economy, the Obama administration has awarded $2.4 billion in grants for battery technology and EVs as part of the American Reinvestment and Recovery Act of 2009 [10]. The money was split up between the various industries involved in the electric vehicle industry. This includes battery manufacturers, automotive companies, lithium-ion battery recyclers, battery accessory companies, and universities. Many Michigan companies as well as several universities have received these grants which will help strengthen Michigan's already strong EV battery production and technology base, reinforcing the feasibility of creating a large scale battery storage facility. Table II shows which Michigan companies and universities have received grant money and the amount received [11].

TABLE 2 AMERICAN RECOVERY AND REINVESTMENT ACT GRANTS AWARDED TO MICHIGAN COMPANIES AND UNIVERSITIES

Company	Award (millions)
Johnson Controls	$299.2
A123	$249.1
Dow Kokam	$161
LG Chem	$151.4
GM Corporation	$105.9
Ford Motor Company	$62.7
Chrysler	$48
Magna E-Car Systems of America, Inc.	$40
Toda America, Inc.	$35
H&T Waterbury DBA Bouffard Metal	$5
Wayne State University	$5
Michigan Technological University	$2.98
University of Michigan	$2.5

The Battery Bank Facility

The facility will acquire manufacturing reject batteries that are still usable but are unsuitable for vehicles. Sufficient lead up time to prepare the facility will be allowed as the natural degradation of consumer EV batteries will require several years of use. Currently, General Motors is issuing an 8 year/100,000 mile warranty to consumers for their battery pack [12]. Similarly, the anticipated Toyota Prius plug-in hybrid will come with an 8 year/100,000 mile warranty [13]. Most battery packs will likely outlive their warranties, limiting initial battery acquisition until several years after consumer use begins.

Accumulation of Battery Packs in the Facility

Initial battery acquisition will require considerable time as the new EV batteries will remain in working condition for several years. The first series of EV batteries will become available around 2021, as illustrated in Fig. 4.

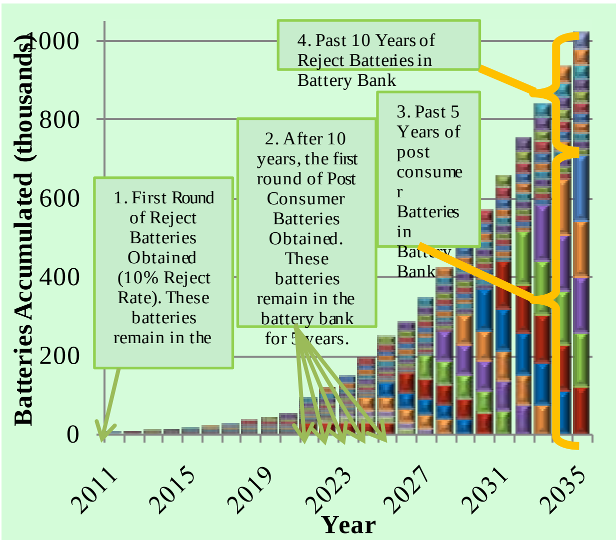

FIG. 4 BATTERIES ACCUMULATED IN THE BATTERY FACILITY THROUGH 2035

Until 2021, only reject batteries from manufacturers will be collected for the battery facility. Reject batteries are assumed to be collected at a 10% rejection rate from the manufacturer. These batteries will last for approximately 10 years within the facility. Manufacturer reject batteries will enter the storage facility in a condition similar to the post-consumer EV batteries. The key difference between the manufacturer reject and post-consumer batteries will be the number of cycled discharges the batteries have sustained. When a consumer EV battery pack reaches the end of effective lifespan, the battery will be transported to the battery facility for further use. Approximately 5 years after introducing post-consumer EV batteries to the facility, they become completely degraded and may then be recycled or sent in for repair. Manufacturing reject batteries are projected to last 10-15 years in the battery facility.

Battery Facility Capacity

The capacity of the battery facility will depend on the remaining capacity of the battery packs stored within. Currently, the Nissan Leaf and Chevrolet Volt are the primary EVs available with new models from additional manufacturers available in the future. The capacity of the Leaf battery is 24 kWh, and the Volt battery is 16 kWh. It is assumed that by the time the battery has degraded past its useful life in a consumer vehicle, it is down to 50% of its original capacity. This puts the Leaf battery pack at 12 kWh by the time it arrives in the facility, and the Volt battery pack at 8 kWh. Other battery packs exist, such as the Toyota Prius's after market alteration Hymotion kit by A123 rated at 5 kWh (maximum capacity). The battery storage facility will contain a mixture of new and old battery packs within the facility; the average capacity will vary over time as emerging technologies will increase the energy density of newer battery packs. As an initial conservative figure, our figures assume an average battery pack capacity within the facility as 5 kWh.

By 2035, there will be approximately 1,016,000 battery packs within the facility. Assuming the battery packs have an average capacity of 5 kWh per pack, the battery facility will hold a capacity of 5.1 GWh that can be discharged from the facility during on-peak periods and recharged during off-peak periods. Fig. 5 shows the capacity of the battery facility as battery packs are accumulated through 2035.

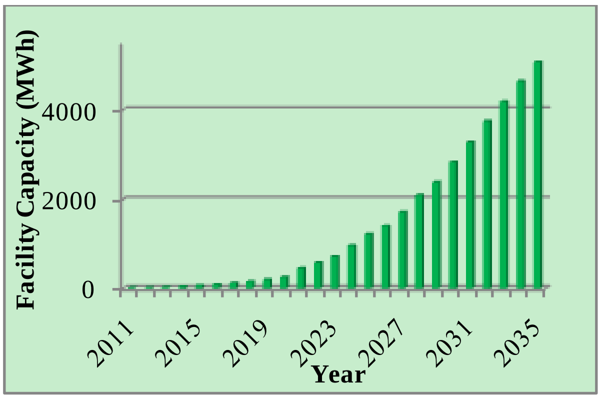

FIG. 5 MWH CAPACITY OF THE FACILITY AS BATTERY PACKS ARE ACCUMULATED

If the battery facility is charged to full capacity and discharged with 5.1 GWh of wind energy each day, 465 GWh of electricity from the wind would be required annually, assuming 25% wind capacity factor. According to the RPS figures described in Table I, Michigan wind energy will be sufficient to meet this criterion, as 11,155 GWh of renewable energy must be available annually by 2015.

Recognizing the Design Issues

If the proposed facility is to hold 1,016,000 battery packs by 2035, an exceptionally large facility will be necessary. In order to estimate the facility's proper size, adequate knowledge of current battery pack geometry will be required. Today, the Nissan Leaf and the Chevrolet Volt are the two primary EVs in production. Their respective battery packs can be seen in Fig. 6. Their approximate sizes are:

- Leaf battery: 5 ft x 4 ft x 1 ft
- T-shaped Volt battery: 6 ft x 3 ft x 1 ft

FIG. 6 NISSAN LEAF BATTERY, LEFT, CHEVROLET VOLT BATTERY, RIGHT

Storage space for the batteries will require additional room for other system mechanics. Some of these systems will include wiring, cooling, and storage systems. Once these additional systems are factored in, each battery will require roughly 30 ft^3. At 30 ft^3, the facility will require, at minimum, 30,480,000 ft^3 to accommodate the battery packs accumulated by 2035. The battery packs would be stacked on shelves no more than 20 ft high, requiring the facility to occupy an area of land of approximately 1,524,000 square feet, or about 35 acres.

Thermal Management

A facility of this magnitude in size containing over one million battery packs will have a significant heat concern. Typically when a battery is resting, even if it contains a charge, no heat is generated. The heat generation comes from charging and discharging of the batteries. The immense heat generation caused by the batteries will actually cause the batteries to degrade quicker. In some cases, the heat will disable the batteries from being able to charge or discharge; these battery packs are manufactured with built in temperature sensors which cause them to stop functioning if the temperature gets to high [14]. The reason is because batteries are pressurized vessels which if allowed to get too hot will risk exploding from over-pressure.

A standard wall socket delivers 120V at an efficiency of 80-90% and circuit breakers regulate current at 15 amps. As $P = V * I$, the theoretical rate of charging is 1800 W. Assuming a 15% loss of electricity due to inefficiency, 270 W, the actual rate of charge for the batteries will be approximately 1530 W. As the battery packs average 5 kWh, or 5000 Wh, each battery pack will require approximately 3.3 hours to reach a full charge.

If heat is generated at a rate of 270 W while charging, each battery pack will generate 890 Wh of heat over the course of 3.3 hours, or, approximately 3040 BTU's. To counteract the heat generated by recharging the batteries, an equivalent amount of cooling would be required from air conditioning and ventilation while also using perforated floors.

Managing temperature and heat generation are not new problems; computer server farms encounter similar problems with large scale heat generation from their equipment. Even high efficiency server farms spend an additional 40-60% extra on cooling in addition to the power required to run the facility. The impact of cooling such facilities is so great that some companies believe that moving their operations to cold climates such as Iceland or northern Sweden to avoid these costs may be more beneficial [15].

During the winter months, a battery storage facility in Michigan should see reduced cooling costs. During other seasons of the year, cooling costs and requirements will vary based upon variable seasonal weather.

Organization and Monitoring

Managing one million battery packs in a facility poses many unique challenges mechanically and chemically. Battery management will require sophisticated real-time systems in place to monitor battery temperature, and state of charge. An Automated Storage and Retrieval System (AS/RS) would provide the level of battery management necessary for placing new battery packs in the facility and remove completely degraded battery packs. A monitoring system will be placed on each battery to monitor their individual behaviour

while under charging and discharging sessions. The monitoring systems will be connected to a central processing unit that will feed information to the AS/RS, signaling when a battery must be removed for either repair or recycling. Operators will use the AS/RS to add new battery packs to the shelves as necessary.

Many of the lithium ion batteries available today in the EV market are designed very differently. The level of variation within the geometry of each battery, as well as their individual storage capacity, poses many different challenges for charging and discharging the system. Considerable analysis of each battery pack system will be required to appropriately prepare monitoring systems for each battery pack type. If necessary, different sections of the facility will be dedicated to specific battery packs and charging/discharging systems.

Economic Value

Current Midwest Independent Transmission System Operator (MISO) pricing puts the average cost of on-peak electricity in Michigan at $45.84/MWh [16]. MISO is a transparent, non-profit organization that provides reliable information and services to customers in the Midwest region. If the battery facility can charge and discharge the MWh values shown in Fig. 5 on a daily basis for each respective year, the daily revenue can be estimated based on MISO's average on-peak electricity price. Assuming a 25% capacity factor for wind, the annual revenue of such a facility for each year from 2011 to 2035 is shown in Fig. 7.

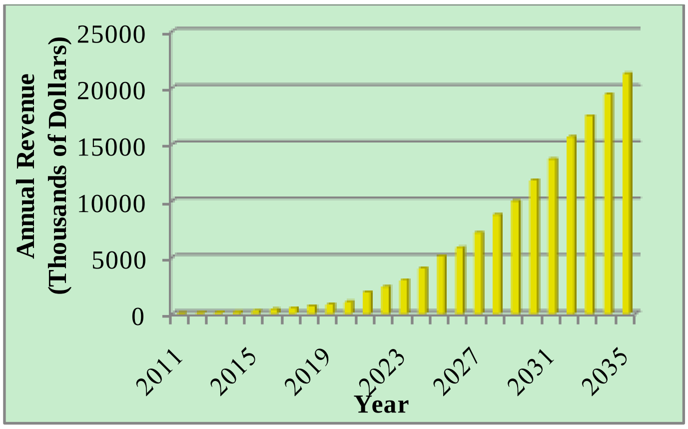

FIG. 7 ANNUAL REVENUE IN THOUSANDS OF DOLLARS (USD) GENERATED BY THE BATTERY FACILITY AS IT ACCUMULATES BATTERY PACKS THROUGH 2035

For example, by 2035, the battery facility will have a maximum capacity available for discharge of 5100 MWh (5.1 GWh) of electricity daily by 2035. This will provide daily revenue of approximately $233,000. Assuming a 25% capacity factor for wind, the battery storage facility could generate approximately $21.3 million annually.

Many factors will come into consideration when examining the necessary expenses of running a facility of this potential size. The two primary expenses for a facility of this magnitude will include initial capital cost, labor, maintenance, and land acquisition associated with the expansion of the facility.

Conclusions

Michigan possesses sufficient wind energy potential to supply a large scale battery storage facility with the necessary energy to assist with on-peak grid stabilization. Additionally, the manufacturing sector of high capacity EV batteries also has solidified its manufacturing base in southwest and western Michigan. This helps to create the environment necessary for a cycle of battery production and recycling, helping to extend the useable lifespan of these batteries in both post-consumer and manufacturing reject capacities.

Current projections indicate that reject batteries should be available for the storage facility with the first round of vehicle batteries available by 2021. The initial capacity of the storage facility will be generally small in scale. As batteries become ever increasingly available, the total capacity of the facility has the ability to expand considerably.

REFERENCES

PA 295 energy plan cases. (2008, October 6). Retrieved from State of Michigan: http://www.michigan.gov/mpsc/0,4639,7-159-52495_53472---,00.html

Synapse Energy Economics Inc. (2011). *Energy Future: A Green Alternative for Michigan.* National Resources Defense Council; Energy Foundation.

(2010). *Michigan Electricity Profile.* Energy Information Administration.

(2012). *Annual Energy Outlook Early Release Overview.* Energy Information Administration.

IBM. (2009). The Battery 500 Project. Almaden, California, United States of America.

Argonne National Laboratory. (2009, November). *Argonne to Develop Lithium-Air Battery.* Retrieved from Argonne Transportation Technology R&D Center Website:

http://www.transportation.anl.gov/features/2009 _Li-air_batteries.html

Rahim, S. (2010, May 7). Will Lithium-Air Battery Rescue Electric Car Drivers From 'Range Anxiety'? . *The New York Times*.

Gorshkov, V., & Volkov, O. (2010). *Patent No. US 7,820,137 B2.* United States.

Loveday, E. (2009, August 30). *Lithium Titanate Batteries Offer Exceptional Fast Charging Capabilities*. Retrieved July 10, 2012, from Green Car Reports: http://www.greencarreports.com/news/1034684_lithium-titanate-batteries-offer-exceptional-fast-charging-capabilities

US Congress. (2009, February 13). *The Recovery Act*. Retrieved July 12, 2012, from Recovery.gov: http://www.recovery.gov/about/pages/the_act.aspx

US Department of Energy. (2011, October). *Recovery Act Awards for Electric Drive Vehicle Battery and Component Manufacturing Initiative.* Retrieved July 12, 2012, from US DOE EERE: http://www1.eere.energy.gov/recovery/pdfs/battery_awardee_list.pdf

GM-Volt: Battery, Warranty. (2011). Retrieved from GM-Volt Discussion Board: http://gm-volt.com/2010/07/19/chevrolet-volt-battery-warranty-details-and-clarifications/

Toyota USA Newsroom. (2011, December 5). Retrieved from Toyota Motor Corporation Website: http://pressroom.toyota.com/releases/toyota+introduces+2012+prius+plug-in+hybrid.htm

Electrochem Commercial Power. (2006, Sebtember 19). Safety and Handling Guidlines for Electrochem Lithium Batteries.

Hancock, S. (2009, October 9). Iceland Looks to Serve the World. *BBC News* .

(2012). *Real-Time Pricing Report*. Midwest Independent Transmission System Operator (MISO).

John A. Patten has over 30 years of precision machining experience, 40 years of industrial experience, and 10 years in the project management trade. His work experience includes very large, medium and small companies and businesses (General Motors from 1971-1978 and, more recently, Micro-LAM 2011-present). Dr. Patten has been involved in most phases of product and process development for new and existing products during his career. This work has spanned from product and process R&D through delivery. Proposal development and specifications have been an integral activity throughout his career, and he has consistently not just met but exceeded customer requirements and expectations. Dr. Patten has managed numerous projects in the 1/2 to 1 million dollar range throughout his industrial and academic career. Most recently he managed a $972,000 US Department Of Education project (the Green Manufacturing Initiative, 2009-2012), which included two full time staff members, over 20 students/interns, and more than half a dozen faculty contributors. As a result of this effort, successful projects were implemented in over a dozen companies (with multiple projects at some of the companies) ultimately resulting in the successful formation of the Green Manufacturing Industrial Consortium, modeled after the NSF I/UCRC program.

Nathan J. Christensen is a masters graduate student at Western Michigan University working towards a degree in Manufacturing Engineering. His areas of study also include Environmental Science and Mechanical Design. Nathan has worked for several years on research projects involving energy storage and distribution in lithium ion batteries, electric vehicles, wind energy, and other green manufacturing based initiatives in energy and material efficiency. He has served as both a speaker and presenter at conferences and other events in Michigan.

Andrew J. Gabriel is a Western Michigan University graduate with a bachelor degree in Chemical Engineering – energy management. His work background through the Green Manufacturing Initiative & Industrial Consortium encompasses energy distribution and efficiency as well as various other industrial projects. Andrew has served as a speaker, presenter, and panelist for events in Michigan and is currently employed by Armstrong International as a Solutions Engineer.